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IRRIGATION EXPERIMENTS WITH GRAPES

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HOW does irrigation affect growth and other characteristics of your grapes?

This bulletin is a report of new and extensive work on the comparative responses of grapes ***with*** and ***without*** irrigation. Here are the major findings:

- Irrigation ***did not affect*** appearance, flavor, keeping quality, or drying ratio of the table and raisin varieties tested.
- Irrigation ***did affect*** berry size and yields (but not beyond natural capacity of the vines). Berries were ***smaller*** in the dry plots—where soil moisture had been kept down at the permanent wilting percentage (PWP) for long periods during the growing season. However, there were slight delays in fruit maturity in a few cases in the continuously moist plots.
- Irrigation ***did not affect*** wine quality, if all fruit was allowed to mature. Note: the smaller berries from the PWP plots produced wines of darker color.

WHEN do grapes need irrigation?

- When the soil in contact with the roots has been allowed to reach the PWP. Best irrigation practice is to withhold water until ***readily available soil moisture is nearly depleted.***
- Check page 30 for proper irrigation intervals for your locality.

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IRRIGATION EXPERIMENTS WITH GRAPES

THIS REPORT deals with a series of experiments on the effects of irrigating grapes. These experiments were conducted under widely different climatic conditions, ranging from the hot, dry climate of the southern San Joaquin Valley, to the cool regions in the central coast counties. These experimental plots were located in seven grape-growing areas on six soil types, which varied from sands of low water-holding properties to loams of moderate to high moisture characteristics. The grapes under trial included raisin, table, and wine varieties.

THE PROBLEM

Although grapes have long been one of the principal crops in California there is comparatively little published information on the responses of vines to irrigation. In 1901 (3),[1] Bioletti and Twight reported an irrigated vineyard in the Santa Clara Valley that produced four times the crop of an adjoining unirrigated one. This was during the four-year drought that followed the heavy crops of 1896–97. Bioletti (1) later stated: "It was long believed that it was impossible to make good wine from irrigated vineyards. But this is no more true than the equally widespread belief that irrigation is incompatible with the production of other good fruit." Still later Bioletti (2) published general recommendations for the irrigation of vineyards. Hendrickson and Veihmeyer (4) published results obtained in irrigation experiments with Thompson Seedless and Emperor grapes. These results showed that the growth and fruiting of grapevines proceed in a normal manner if the supply of readily available moisture is maintained throughout the season. Jacob (5) has since discussed the general principles of the irrigation of vineyards.

The experiments reported in this bulletin are the result of continued work on the problem of how irrigation affects yields, growth, sugar and acid contents, storage properties, and drying ratios of grapes, as well as the quality of wines.

PROCEDURE

The general procedure in conducting the experiments was essentially similar to that used in our work with other fruits (9). Ordinarily one plot was kept supplied with readily available moisture, while another was left unirrigated for relatively long periods or until certain responses indicating water deficiencies were obtained in the appearance of the foliage or fruit. In some cases a third plot was used in which the vines were irrigated, but less often than those kept continually supplied, and were thus for short periods without readily available moisture. At harvest time suitable samples of fruit were picked and used in storage, drying, or winemaking tests depending on the variety.

One hundred berries in each plot were marked and measured at regular intervals with precision calipers for size records. Yield records were obtained in a few

[1] See "Literature Cited," p. 31, for references referred to in the text by number.

cases, but experience with other fruits has shown that yield records are of limited value unless they can be secured over a period of many years, because of the variability that is common to fruit trees.

At the beginning of each experiment large composite samples of soil were secured from several locations in each plot. These samples were generally taken foot by foot to a depth of 6 feet. From this stock supply the *moisture equivalents* and the *permanent wilting percentages* (*PWP*) were ascertained before field work started. The moisture equivalents were found by means of a soil centrifuge in the usual manner (9), and PWPs were found by growing and wilting sunflower plants in sealed containers of the samples.

Graphs and tables

Some of the results of the experiments are presented graphically and others in tabular form. The soil moisture record and the growth of fruit during a typical season are given graphically for each experiment. Growth of fruit is plotted as average diameters in centimeters on each date of measurement. The soil moisture record is shown as percentages of moisture on the sampling dates. Reading across, the peaks in the curves indicate the increases in soil moisture due to irrigations; reading down, they show the depth to which the water penetrated. The PWPs are shown by the short dotted lines on the left in each diagram. All soil moisture percentages are based on the oven-dry weight of the soil. These data are given graphically to emphasize the importance of maintaining the supply of readily available moisture—as was done in the irrigated plots in contrast to the unirrigated ones, where the supply was exhausted for considerable periods.

Each experiment also gives tables for (1) soil determinations, (2) comparative sizes, yields, and quality of grapes at maturity, and drying ratios for raisins, and (3) wine analyses in the case of wine grapes.

Throughout this report an effort has been made to emphasize the presence or absence of readily available soil moisture, rather than the number of irrigations or the amount of water applied. The number of irrigations applied in the interior valleys may not be necessary in the cool coastal areas. In either case the continuity of readily available moisture was the important factor. Dry soil conditions between irrigations were indicated by the responses of vines and fruit, particularly if the dry soil conditions were allowed to persist for more than a few days.

TO DEFINE OUR TERMS . . .

Field capacity is the amount of moisture a drained soil can hold two or three days after a rain or irrigation.

Moisture equivalent is a laboratory measurement which closely corresponds to field capacity, except in the case of some sandy soils, where field capacity is slightly higher. Direct field capacity measurement is not always practical.

Permanent wilting percentage (PWP) is the soil moisture condition, measured in percentage, at which the leaves wilt and the plants cannot obtain enough moisture to grow normally.

Readily available moisture is that fraction of soil moisture between the field capacity and the PWP (7, 8). This is the moisture that plants can take up. In the following experiments, the presence of readily available moisture is determined at each depth of soil and for each period by comparing the PWP with the percentage of soil moisture.

Thompson Seedless

Irrigation experiments were carried on with Thompson Seedless (Sultanina) grapes for three years on a Fresno sandy loam at the Wood vineyard near Hughson, Stanislaus County, California. The three plots contained 30 vines each with two guard rows between plots. All cultural treatments of the plots were carried on by the owner, and were representative of the usual vineyard practice in the district. The only variation in treatment was in irrigating.

Soil samples in 1-foot increments to a depth of 5 feet were taken at weekly or bi-weekly intervals in sufficient numbers to give a reliable soil-moisture record of the plots during the growing season. The samples were dried for 48 hours at 105 to 110° C, and the moisture contents calculated on the dry weight of the soil. Three irrigation treatments were used. Treatment A was irrigated frequently between the latter part of May and the time the grapes were ripe which was usually early in September; treatment B was irrigated once each growing season about the middle of June; and treatment C received from one to three irrigations. In other words, treatment A was kept moist continuously, and did not reach the permanent wilting percentage at any time; B was allowed to reach the permanent wilting percentage and remain there for several weeks before picking; while the treatment given to C varied from year to year.

Table 1. Moisture equivalents and PWPs of Fresno sandy loam soil. Experiments with Thompson Seedless grapes, Wood vineyard, Hughson.

Depth of soil in feet	Moisture equivalent	PWP
0–1	10.4	3.2
1–2	10.3	3.3
2–3	10.7	3.4
3–4	12.4	3.5
4–5	13.9	3.5

The soil on which the experiments were conducted is classified in the Soil Survey of the United States Department of Agriculture as a Fresno sandy loam. It is fairly uniform in texture to a depth of about 5 feet where there is a layer of hardpan. The water-holding characteristics are given in table 1. The table shows that, while the soil does not hold a large quantity of water, a major portion of the water is available to plants.

The soil moisture record during the second year, a typical year, is shown in figure 1. Treatment A was kept above the PWP in the top 5 feet of soil, except for a brief period in the first foot early in the season. This treatment received five irrigations. The soil in treatment B was reduced to the PWP in the top 3 feet early in June and remained there until irrigated on the 17th. It was again reduced to the PWP about July 21. The flattened portion of the moisture curve for B indicates that practically no soil moisture was removed from the 2d and 3d feet after July 21 and but very little from the 4th and 5th. The peak in the B treatment curve in the first foot on August 5 was due to the accidental watering of a portion of the plot, but, as the water penetrated only a few inches, no response was observed either in the vines or fruit. Treatment C was irrigated the same as treatment A until the middle of June. The last irrigation was applied to treatment C early in August, and its soil moisture content was reduced to the PWP in the upper 4 feet on August 26, about one week before harvest. Thus, widely different soil moisture conditions existed in the three plots during a large part of the growing season. The soil in treatment A was kept continuously moist, that in B was allowed to become dry a long time before picking,

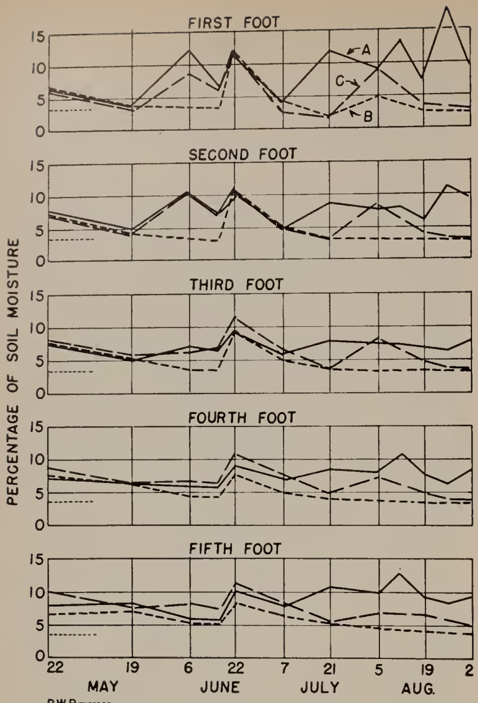


Fig. 1. Soil moisture conditions in the Wood vineyard, second year of trials. The PWP is indicated by the dotted lines at the left. Treatment A was irrigated June 4, June 17, July 18, August 11, and August 25; treatment B, June 17; and treatment C, June 4, June 17, and August 2.

while that in C was not allowed to dry out until about one week before harvest.

Growth of the fruit was obtained by measuring 5 berries on each of 20 bunches in each plot. The growth curves of the Thompson Seedless grapes in the second year are given in figure 2. The berries in treatment B were slightly smaller than those in treatments A and C. The differences in size of the grapes in all three plots were on the borderline of statistical significance up to July 21. Thereafter, the diameters of the berries in treatment B were significantly smaller than those in treatment A. The soil moisture in the upper 3 feet in treatment B was reduced to the PWP at this time The cause of the slow growth of fruit in treatment C is unknown, but was not due to lack of readily available moisture, as the moisture conditions were essentially the same as in treatment A.

Determinations of the total soluble solids (approximately the sugar content) by Balling hydrometer readings on expressed juice, and of the acid contents by titration, were made during the latter part of the growing season each year. Figure 3 shows that the sugar contents of A and C in the second year were about one degree Balling lower than B, and that this difference became larger up to the date of picking, September 2, when it was a little over 2 degrees. (Table 2 shows, however, that sugar contents were practically identical for A, B, and C in the first year.) The curves for the acid contents show a fairly regular decrease during the season. On September 2 the acid content of the fruit in treatment A was slightly higher than those from the other treatments. The vigorous growth in treatment A may have been a factor in retarding the ripening of the fruit in this treatment. The grapes were probably picked before they were fully mature.

The irrigation treatment had a pronounced effect on the yields. The average yield from treatment A in the second year

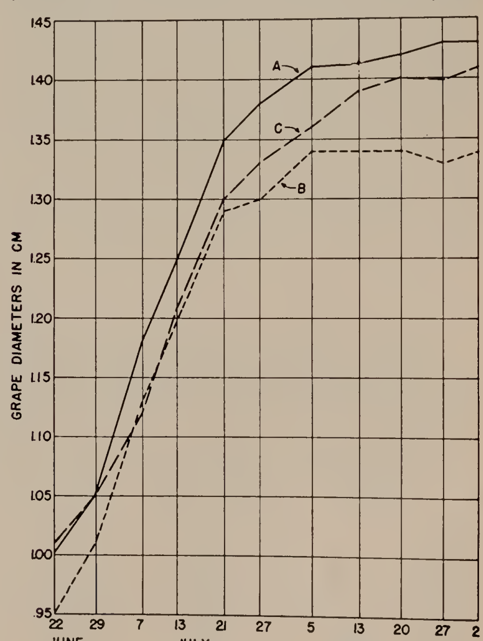


Fig. 2. Sizes of Thompson Seedless grapes, Wood vineyard. Second year of trials.

was 32 pounds per vine; treatment B, 22 pounds; and treatment C, 28 pounds.

The ratios between the weights of fresh fruit and of raisins were obtained by drying about 26 pounds of fruit from each treatment in a small dehydrater in which the temperatures were carefully controlled at from 130 to 140° F. The drying ratios obtained were 4.1 for treatment A, 3.7 for B, and 3.7 for C. It will be seen that the drying ratios correspond, approximately, to the total soluble solids content.

The sizes, yields, and quality of Thompson Seedless grapes in the three-year experimental period, as well as Balling and acid contents for all years, are given in table 2.

Storage. Three pickings of fruit made at weekly intervals were used in storage tests. These pickings were divided into four lots and stored at the following temperatures: (1) 32° F, (2) 50° F, (3) 32° F for two weeks followed by room temperature, and (4) 50° F for two weeks and then kept at room temperature. When held continuously for two months at 32° or 50°, the fruit from all treatments showed no variations in keeping quality. Of the fruit held first in cold storage and then exposed to room temperatures, that from treatment A, the continuously moist plot, kept on the average from one to three days longer than that from the other treatments. Generally, the keeping qualities of the grapes were not materially affected by high soil moisture conditions during the ripening period.

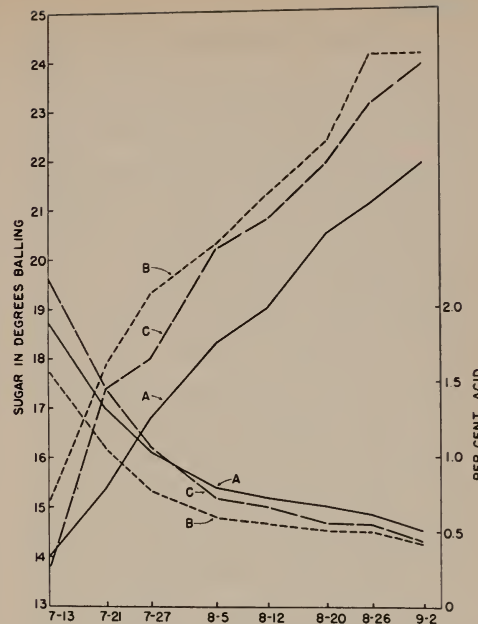


Fig. 3. Balling and acid contents of Thompson Seedless grapes, Wood vineyard. Second year of trials.

Table 2. Characteristics of Thompson Seedless grapes, Wood vineyard, Hughson.

Treatment	Balling (degrees)	Acid as tartaric (per cent)	Av. diameter (cm.)	Av. yield (lbs. per vine)	Drying ratio
A 1st year	22.4	0.53	1.73†	....	3.9*
B 1st year	22.4	0.45	1.85†	....	3.9
C 1st year	22.0	0.47	1.85†	....	3.9
A 2nd year	21.9	0.51	1.43	31.9	4.1
B 2nd year	23.9	0.42	1.34	22.3	3.7
C 2nd year	24.1	0.44	1.41	27.8	3.7
A 3rd year	22.6	0.62	1.34	34.8	3.5
B 3rd year	23.4	0.56	1.34	26.8	3.3
C 3rd year	25.3	0.56	1.32	20.4	3.2

* Pounds of fresh fruit to make 1 pound of raisins.
† Weight in grams.

Muscat

Experiments with Muscat of Alexandria grapes were carried on for four years in the University of California vineyard, at Davis. Each plot consisted of a row of 33 vines surrounded on the sides and ends by guard vines. The vines were planted 6 × 12 feet and were 12 years old at the beginning of the experiment.

Soil samples were taken frequently during the growing season in one foot increments to a depth of 6 feet, and several times in 3 foot increments between the 6 and 12 foot depths. The moisture content varied so slightly between 6 and 12 feet that it was deemed unnecessary to take samples at this depth as often as they were taken in the top 6 feet of soil. The soil on which these experiments were conducted is classified as a Yolo loam and is fairly uniform to about 6 feet. Below 6 feet occasional pockets of sand or fine gravel are encountered that tend to make the moisture extraction curves at these depths somewhat erratic. The changes in soil moisture below 6 feet apparently had no effect on the responses of the vines to the different irrigation treatment. The apparent specific gravity of the soil was about 1.3. The other water-holding properties are given in table 3.

Three irrigation treatments were used. Treatment A was kept moist continuously, with four irrigations during the growing season except in the first year when two irrigations were applied. Treatment B was the dry treatment and was not irrigated during the growing season. Treatment C was intermediate between A and B and received an average of two irrigations during the season.

Table 3. Moisture equivalents and PWPs of Yolo loam soil. Experiments with Muscats, University of California vineyard, Davis.

Depth of soil in feet	Moisture equivalent	PWP
0–1	17.0	7.6
1–2	16.3	9.1
2–3	16.6	10.4
3–4	20.7	10.8
4–5	20.9	9.3
5–6	17.4	10.8

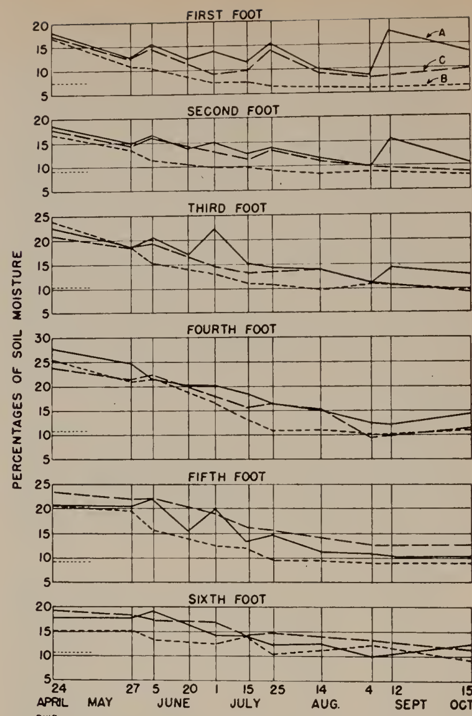


Fig. 4. Soil moisture conditions in the University of California vineyard at Davis, fourth year of trials. The PWP is indicated by the dotted lines at the left. Treatment A was irrigated May 27, June 20, July 22, and September 5; treatment B was not irrigated; treatment C was irrigated May 27 and July 22.

Treatment A was maintained above the PWP in all years, except, occasionally, in the top foot of soil for a few days. The readily available moisture in the top 3 feet in treatment B was exhausted on different dates from early in July to early in August depending on climatic conditions during the season. Treatment C was generally reduced to the PWP a short time before harvest. In general, treatment A had readily available moisture throughout the season; B was without it for a long period; C was without it for a comparatively short time just before harvest.

The soil moisture record for the fourth year is shown in figure 4. Treatment A was above the PWP during the season except in the 5th and 6th foot depths about the middle of September. Treatment B reached the PWP in the first 2 feet about July 1; in the 3d foot, about July 15, and in the 4th and 5th foot depths late in July. Treatment C reached the PWP in the top 4 feet early in September.

Growth of fruit made during the fourth year of the experiment is shown in figure 5. Muscat grapes show distinctly three periods of growth. The first, a period of rapid enlargement, was in progress from June 13 to about July 3. From the latter date until August 8 the growth was fairly slow, after which rapid growth was resumed during the final period. The berries in all plots reached the maximum size late in August. The fruit in treatment B began growing more slowly than that in the other two plots early in July when a lack of readily available moisture in the top 2 feet was indicated by the flattening of the curves. After July 11 the fruit in treatment B was smaller than that in the other two plots. The soil moisture in treatment C apparently reached the PWP after the fruit had attained maximum size.

A summary of total soluble solids and acid contents, yields, sizes, and drying ratios obtained over the four-year period are given in table 4. Variations in sugar and acid contents in each year's trial are not high enough to be attributed to irrigation treatment. Likewise, the drying ratios are approximately the same in a given year, except in two cases where some drying took place on the vines before the grapes were harvested. Treatment B (dry) consistently produced the lowest yields and the smallest berries. Yields from B were significantly smaller than the other yields. The size of berries in B was significantly smaller than A and C during three seasons, and significantly less than C during the fourth.

The Muscat grapes in this experiment were used for drying to raisins, and were left on the vines until they had a comparatively high sugar content. The grapes in the unirrigated plots generally increased in sugar content late in the summer faster than those in the irrigated

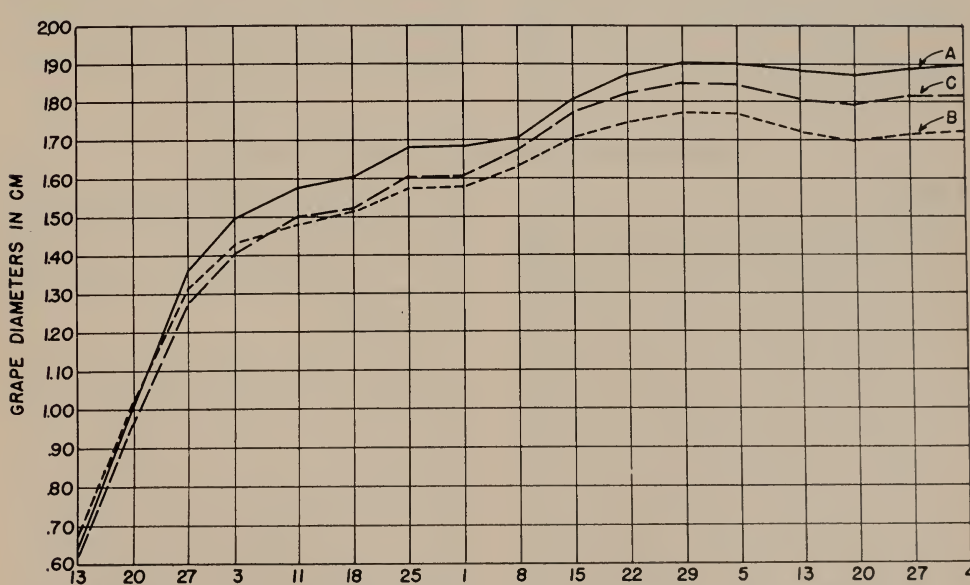


Fig. 5. Sizes of Muscat grapes, University of California vineyard at Davis. Fourth year of trials.

Table 4. Characteristics of Muscat grapes, University of California vineyard, Davis.

Treatment	Balling (degrees)	Acid as tartaric (per cent)	Av. diameter (cm.)	Av. yield (kilos per vine)	Drying ratio
A 1st year	23.5	0.52	1.79	15.0	3.5
B 1st year	23.1	0.45	1.58	8.5	3.0*
C 1st year	23.9	0.50	1.71	10.8	3.1*
A 2nd year	22.7	0.50	1.79	14.9	3.3
B 2nd year	21.0	0.54	1.77	9.7	3.6
C 2nd year	23.7	0.52	1.86	15.9	3.4
A 3rd year	26.9	0.37	1.88	13.9	3.3
B 3rd year	27.9	0.30	1.68	2.6	3.2
C 3rd year	27.3	0.38	1.91	14.9	3.1
A 4th year	21.5	0.63	1.90	27.2	3.9
B 4th year	21.2	0.62	1.77	18.9	3.7*
C 4th year	21.8	0.60	1.85	28.9	3.8*

* Partly dried on vines.

plots, but, if harvest was delayed a short time, the sugar contents of the fruit in the wet plots increased until they were about equal to those of the grapes grown in dry soil. In other words, the fruit from the irrigated plots seemed to mature a little more slowly than that from the unirrigated treatments, but, if left on the vines until fully ripe, it had about the same composition as that from the plots subjected to long periods of dry soil conditions. The vines in the irrigated plots, however, produced more fruit and larger berries than those in the unirrigated ones.

It is interesting to note that although the moisture content of the soil below the 6-foot depth was high throughout the season, the behavior of the vines was influenced chiefly by the soil moisture conditions above that depth.

EXPERIMENTS WITH TABLE GRAPES

Emperor

Experiments were carried on for three years with Emperor grapes in the McClurg vineyard near Sanger, California. The plots consisted of two rows of ten vines each, planted 10 × 10 feet, and were surrounded by guard rows that received the same irrigation treatment as the experimental ones. The soil was a San Joaquin loam underlain with a hardpan at about 5 feet. The moisture-holding properties are given in table 5. The plots were sampled in one-foot increments to a depth of 5 feet at nine points in each plot every two weeks. Cultural treatments were carried on by the owner in accordance with the practice in the district. The soil samples were handled and dried in a similar manner to that described for the Thompson Seedless.

Three irrigation treatments were used. Treatment A was kept supplied with readily available moisture by frequent irrigations during the growing seasons. The irrigations were given so often that the soil in this treatment was above the field capacity for considerable periods and at times was saturated. Treatment B was irrigated either once or twice during the growing season, in an attempt to have

Table 5. Moisture equivalents and PWPs of San Joaquin loam. Experiments with Emperor grapes, McClurg vineyard, Sanger.

Depth of soil in feet	Moisture equivalent	PWP
0–1	7.8	3.0
1–2	8.0	4.2
2–3	9.1	4.4
3–4	9.6	4.9
4–5	10.1	5.5

the readily available moisture exhausted before the grapes had reached full size. Actually this was accomplished only in one year out of three. Treatment C was irrigated a different number of times each of the three seasons but the net results were the same each year, that is, there was readily available moisture present each year until after the grapes had reached full size. The Emperor grapes in the C treatment in this vineyard showed responses that were essentially the same as those in treatment A. In other words, although Emperor grapes are normally picked in late September and October,

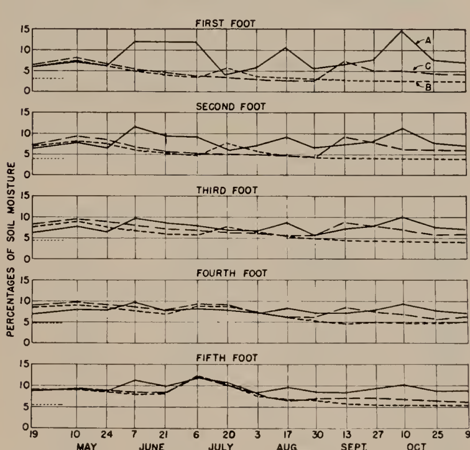


Fig. 6. Soil moisture conditions in the McClurg vineyard, second year of trials. The PWP is indicated by the dotted lines at the left. Treatment A was irrigated May 1, June 5, June 19, July 4, August 3, September 16, and September 27; treatment B, May 1 and July 16; treatment C, May 1 and August 31.

they reach full size early in September and dry soil conditions would have to prevail prior to this time, if variations in size response are to be obtained.

In the second year's trials the soil moisture in treatment A was maintained above the PWP throughout the season (figure 6), except in the first foot for a few days about July 20. In treatment B the soil moisture was reduced to the PWP about August 30 in the 2d, 3d, and 4th feet; and in the 5th foot about September 13. It remained in this condition until after the crop was harvested early in November. The soil moisture in treatment C was reduced to the PWP between June 21 and July 6 only in the 1st foot, but was close to this condition in the 2d foot on July 20, and in the 3d foot on August 12. The supply of readily available moisture was replenished in the other depths by an irrigation on August 31.

In the second year the fruit grew at about the same rate June 7 to August 17, after which the fruit in treatment B did not grow as fast as that in the other two plots (figure 7). The fruit in all treatments reached maximum size for the season about the middle of September, or nearly two months before harvest. The brief soil moisture reductions in treatment C thus did not affect the increase in size of the berries. In treatment B, however, the growth of the berries was affected by the soil moisture conditions prevailing in that plot early in September. The decrease in rate of growth of the fruit agrees closely with the time the readily available moisture was exhausted. The slight decrease in size in treatment A during the last few weeks before harvest may have been due to the fact that the berries were slightly softer than early in the season, and the slight pressure exerted in taking the measure with the calipers may have compressed the fruit.

The total soluble solids and acid contents, sizes, and yields of fruit for the two years are summarized in table 6. The sugar contents of the grapes in treatment

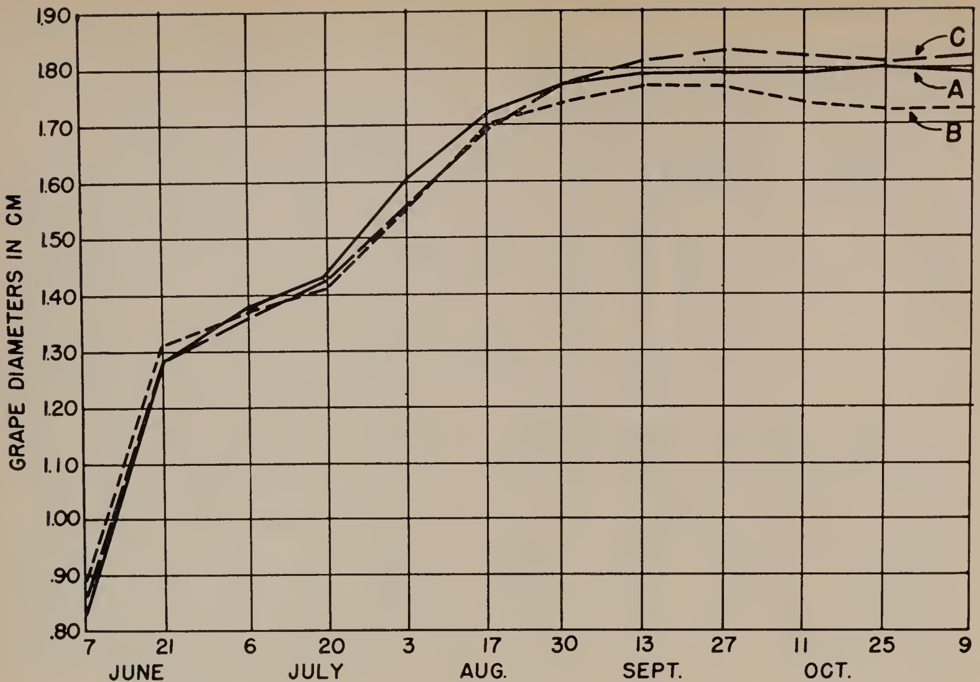


Fig. 7. Sizes of Emperor grapes, McClurg vineyard. Second year of trials.

A were slightly lower than in the other plots, at the end of two seasons, possibly because of the frequent irrigations and lack of adequate drainage which resulted in saturated soil conditions for considerable periods. The acid contents were nearly the same at the end of each season. A slight, but significant, reduction in size of berries occurred in the B treatment in the second year when the soil moisture was reduced to about the PWP before the fruit in that plot reached full size.

Storage. Representative samples were picked from each of the plots during the three-year trials just prior to and during the harvest season. One half of each lot

Table 6. Characteristics of Emperor grapes, McClurg vineyard, Sanger.

Treatment	Balling (degrees)	Acid as tartaric (per cent)	Av. diameter (cm.)	Av. yield (lbs. per vine)
A 1st year	20.2	0.47	1.87	27.7
B 1st year	19.5	0.48	1.88	28.0
C 1st year	20.7	0.47	1.89	21.9
A 2nd year	20.1	0.43	1.79	23.3
B 2nd year	21.4	0.44	1.73	22.5
C 2nd year	21.4	0.40	1.82	29.2
A 3rd year	19.2	0.36	1.90	....
B 3rd year	19.3	0.28	1.89	....
C 3rd year	20.6	0.31	1.85	....

was stored at 32° F and the other half at 50° F. After two weeks at these temperatures small samples were removed from storage at two-week intervals for observation at room temperatures. All lots showed remarkable keeping qualities. Those left in the 32° F room kept in good condition until about the middle of January. No differences in keeping quality that could be attributed to the irrigation treatments were observed.

Thompson Seedless

Experiments were conducted for one year on the irrigation of Thompson Seedless grapes, Young and Derby vineyards, in the Arvin district. The grapes were grown for the early fresh fruit market, and the vines were girdled annually in accordance with the recommendations of the Division of Viticulture of the University of California. The soil was classified as an Arvin loamy fine sand. The moisture equivalents and permanent wilting percentages are given in table 7.

The plots in both vineyards consisted of three rows of 25 vines each, the center row being used as the experimental row while the two outer ones served as guards. All plots were irrigated during the winter, and again in the spring. The vines were girdled about May 15. The irrigated plot in the Young vineyard received water on June 10, June 29, and July 8; and the irrigated one in the Derby vineyard was watered on June 6, June 20, and July 5. In the unirrigated plot of the Derby vineyard the PWP was apparently reached in the top 3 feet on July 23, but not in the 4th, 5th, and 6th foot depths until sometime after the last samples were taken on August 6. The soil moisture record in the Young vineyard is similar to that in the Derby vineyard. The seasonal soil moisture curves for the Derby vineyard are shown in figure 8.

Samples for determination of sugar and acid contents of the fruits were obtained on July 23 and on August 6. The

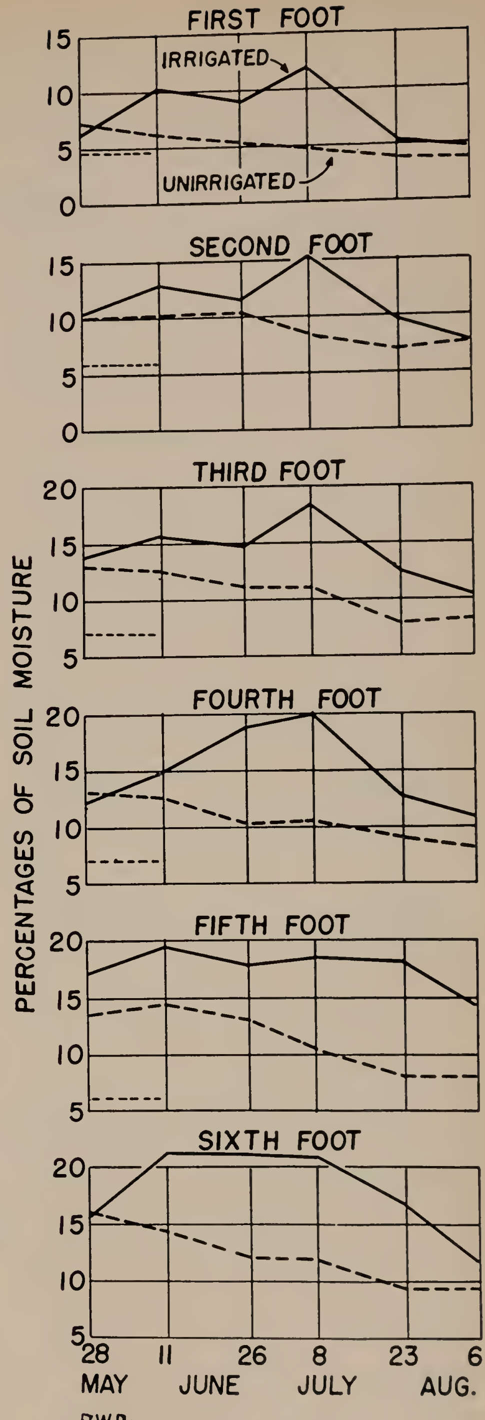


Fig. 8. Soil moisture conditions in the Derby vineyard. The PWP is indicated by the dotted lines at the left. The irrigated plot was watered June 6, June 20, and July 5.

Table 7. Moisture equivalents and PWPs of Arvin loamy fine sand, Young and Derby vineyards, Arvin.

Depth of soil in feet	Young vineyard		Derby vineyard	
	Moisture equivalent	PWP	Moisture equivalent	PWP
0–1	6.0	4.1	9.3	4.6
1–2	7.0	4.5	11.6	5.8
2–3	7.4	4.9	13.3	7.0
3–4	8.7	5.5	12.7	6.8
4–5	10.7	6.0	13.6	6.0

Table 8. Characteristics of Thompson Seedless grapes, Arvin.

Treatment	Date picked	Balling (degrees)	Acid as tartaric (per cent)	Weight per berry (gm.)	Average diameter (cm.)
Young vineyard					
Irrigated	July 25	16.1	0.9	2.39	1.35
Unirrigated	July 25	16.9	0.8	2.53	1.38
Derby vineyard					
Irrigated	August 6	18.9	0.9	2.77	1.43
Unirrigated	August 6	19.3	0.7	2.74	1.41

Table 9. Moisture equivalents, PWPs, and apparent specific gravities of Hanford sandy loam, Diekman vineyard, Lodi.

Depth of soil in feet	Moisture equivalent	PWP	Apparent specific gravity
0–1	7.1	3.4	1.6
1–2	6.7	3.0	1.5
2–3	6.6	2.8	1.6
3–4	6.3	2.7	1.7
4–5	7.0	2.7	1.7
5–6	8.4	2.9	1.7
6–9	6.0	2.9	...
9–12	7.3	3.2	...

results, given in table 8, show no significant differences between treatments.

The average size of fruits found by measuring 200 berries shows that the berries were approximately equal in size. The average diameter measurements and weights are given in table 8.

The results indicate that the irrigations in June and July were unnecessary. In the Derby vineyard the PWP was reached in the top 3 feet about July 23 or just a few days before harvest. There was still readily available moisture in the second 3 feet. The results were similar in the Young vineyard. The irrigations during June and July in the wet plots produced no measurable changes in the fruit, and the maintenance of water high in the available range was needless.

Tokay

Experiments with Tokay grapes, similar to those described for other varieties, were carried on for three years on a Hanford sandy loam soil east of Lodi. Two plots of 16 uniform vines surrounded by guard rows were used. The vines were about 30 years old and planted 10 × 10 feet.

The soil was deep and well drained. The texture was fairly uniform to a depth of 6 feet, but below this depth layers of coarse sand of low water-holding properties were encountered. The soil moisture extraction curves below 6 feet were erratic, due to the variations in texture, and only show that some moisture was used from this depth. The water-holding characteristics are given in table 9. Although the apparent specific gravity was fairly high in the top 6 feet the roots had no difficulty penetrating the soil.

Both plots were irrigated before growth started in the spring to make sure the soil was wet to a depth of 12 feet or more. The dry or unirrigated plot was not irrigated during the growing season. The wet or irrigated plot was watered twice before the crop was picked in the first and third years of the experiment, and three times in the second. The third irrigation was applied in this particular year because of the lateness of the season. Both plots were sampled at bi-weekly intervals to a depth of 6 feet and monthly to 12 feet.

The soil moisture conditions were similar in each of the three years, varying slightly as to dates of irrigation and to dates when the PWP was reached in the different depths. Only the results obtained in the third year are given, and are shown graphically in figure 9. Both plots were irrigated April 15 and the samples on

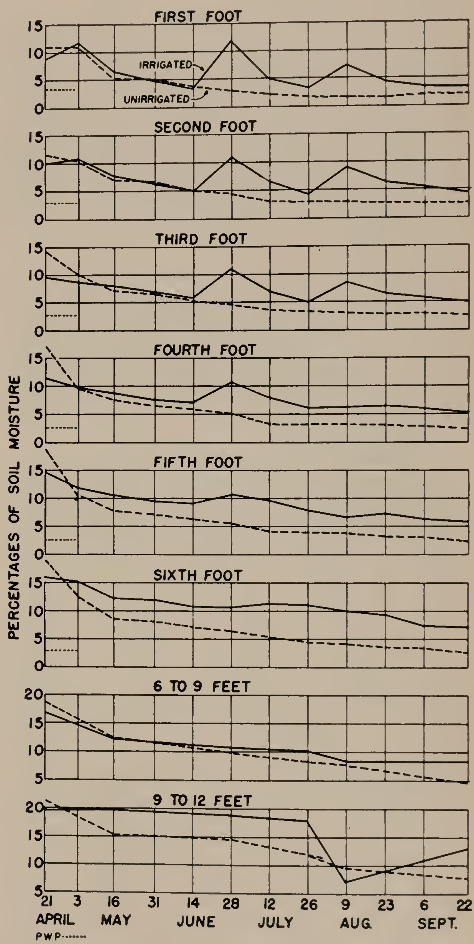


Fig. 9. Soil moisture conditions in the Diekman vineyard, third year of trials. The PWP is indicated by the dotted lines at the left. The irrigated plot was watered April 30, June 27, and August 3. The unirrigated plot was watered April 30, but not thereafter.

April 21 showed the soil moisture to be at field capacity or above in all depths. An irrigation on April 30 increased the moisture contents of the 1st and 2d foot depths. The wet plot was irrigated to a depth of about 5 feet on June 27, and to a depth of 3 feet on August 3. In the dry plot, the soil moisture was reduced to about the PWP on June 14 in the 1st foot; on July 12 in the 2d, 3d, 4th, and 5th foot and on September 6 in the 6th foot. Readily available water was present throughout the season from the 6th to 12th foot depths.

The growth curves of the fruit in the third year are shown in figure 10. The grapes in the dry plot grew more slowly than those in the irrigated one between June 28 and July 12. The soil moisture in the 2d and 6th foot depths in the dry plot was reduced to about the PWP on the latter date.

Although no water was added to the dry plot, the grapes, after July 12, continued to grow about as rapidly as those in the irrigated plot. These vines may have been obtaining water from below the 6th foot depth.

The total soluble solids and acid contents and the measured sizes of the grapes when harvested are given for the three years in table 10. In two years out of three the sugar contents of the grapes from the wet plots were slightly lower than those from the dry. The acid contents were slightly higher each year. The berries from the wet plot were slightly but not significantly larger each year. Tokay grapes are considered ripe enough for shipping when they are well colored and have a total soluble solids content of 17° Balling. The fruit from both plots reached shipping maturity on August 20, the first year; September 21, the second; and August 23, the third. In spite of the marked differences in soil moisture contents in the top 5 or 6 feet for considerable periods during the growing seasons, the principal response was a slight but not significant reduction in size of fruit in the dry plot, while quality as measured by the sugar and acid contents was comparatively unaffected.

Storage. Every year three boxes of grapes were picked from each plot for storage trials. Observations on color and general condition were made, and total soluble solids and acid contents deter-

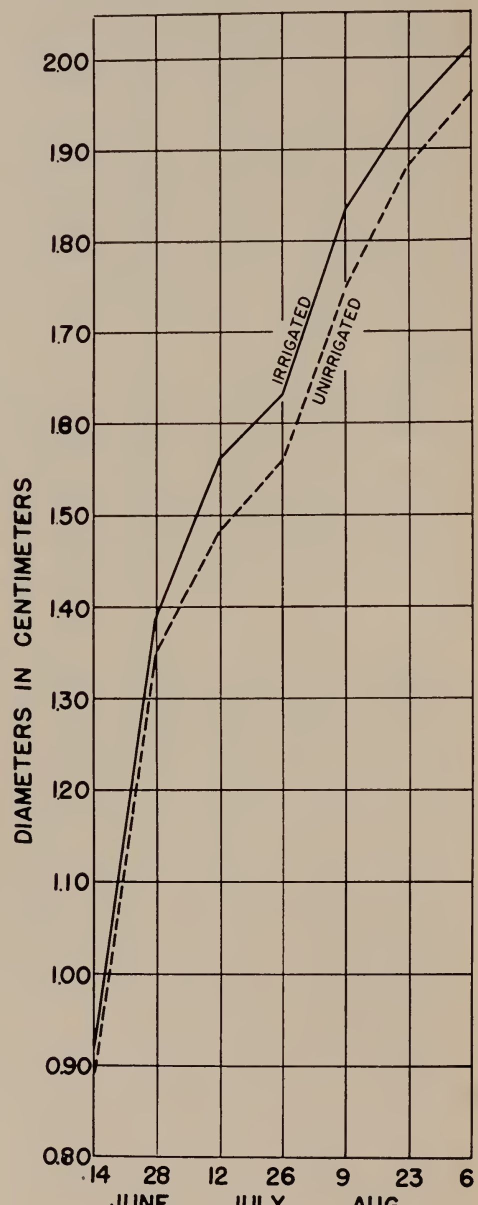


Fig. 10. Sizes of Tokay grapes, Diekman vineyard. Third year of trials.

mined. After several months in storage these observations and determinations were repeated. The results are given in table 11. In general, at the end of the storage period, the sugar and acid contents were essentially equal and the condition of the fruit approximately alike for both plots. The color, however, of the fruit from the dry plot was better than that from the irrigated one.

Table 10. Characteristics of Tokay grapes, Diekman vineyard, Lodi.

Treatment	Date picked	Balling (degrees)	Acid as tartaric (per cent)	Average diameter (cm.)
Irrigated	1st year Aug. 26	19.1	0.49	1.90
Unirrigated	1st year Aug. 26	20.0	0.39	1.89
Irrigated	2nd year Sept. 21	17.2	0.47	2.00
Unirrigated	2nd year Sept. 21	17.9	0.37	1.90
Irrigated	3rd year Sept. 22	23.2	0.52	2.01
Unirrigated	3rd year Sept. 22	22.2	0.45	1.96

Table 11. Storage tests of Tokay grapes, Diekman vineyard, Lodi.

Start of test						
	1st year picked Sept. 23		2nd year picked Sept. 21		3rd year picked Sept. 22	
	Irrigated	Unirrigated	Irrigated	Unirrigated	Irrigated	Unirrigated
Balling (degrees)	21.2	21.6	17.2	17.9	23.2	22.2
Acid as tartaric (per cent)	.....	.....	0.47	0.37	0.52	0.45
Stems	green	green				
Berries	sound	sound				
Color	light	brilliant				
End of test						
	November 1		December 23		November 22	
	Irrigated	Unirrigated	Irrigated	Unirrigated	Irrigated	Unirrigated
Balling (degrees)	20.4	20.3	19.5	19.1	19.9	21.2
Acid as tartaric (per cent)	0.48	0.40	0.48	0.39	0.46	0.39
Stems	85% green	85% green	.....	.....	good	good
Berries	3.4% rot	2.4% rot	.....	.....	slight mold	slight mold
Color	Irrig. less than unirrigated		Irrig. had better color than unirrig.		Irrig. poorer color than unirrigated	

Carignane

Leek vineyard. Experiments with Carignane grapes were carried on for three years, in the Leek vineyard at Hughson, on a Fresno sandy loam similar to the soil used in the trials with Thompson Seedless (p. 5). Three treatments were again used, and the experiments were carried out in the same manner as those previously described. Carignane is a wine variety and the experiments were planned to test the effect of various irrigation treatments on the quality of the wine.

The soil was classified as a Fresno sandy loam with hardpan at a depth of about 5 feet. The water-holding properties are given in table 12.

Three irrigation treatments were used. Treatment A was irrigated four or five times during the season before picking, or sufficiently often to keep the soil moisture above the PWP; during two of the years treatment B was allowed to reach the PWP for short periods before being irrigated, but it was left without irrigation the third year; treatment C was irrigated two or three times or just frequently enough to maintain readily available moisture except for a short period before harvest.

The soil moisture record for the third year is shown in figure 11. The four irrigations given treatment A were sufficient to keep the soil moisture above the PWP during the growing season. In treatment B, the readily available moisture was exhausted from the top foot on June 22 and from the 2d, 3d, 4th, and 5th feet on July 6. Treatment C did not reach the PWP, except possibly in the 1st foot on June 22, until about the middle of September.

Table 12. Moisture equivalents and PWPs of Fresno sandy loam. Experiments with Carignane grapes, Leek vineyard, Hughson.

Depth of soil in feet	Moisture equivalent	PWP
0–1	9.3	2.7
1–2	8.3	2.6
2–3	8.3	2.7
3–4	8.2	2.7
4–5	8.6	3.0

The dry period for the third year in treatment B, beginning early in July, was reflected in the growth of the grapes, figure 12. The fruit in this plot was about equal in size to that in the other plots until July 6 when it was smaller but not significantly so. It remained smaller during the rest of the season. There was no significant difference in size of fruit in treatments A and C.

The total soluble solids and acid contents and yields of Carignane grapes at harvest time are given in table 13. The size of the berries in B was significantly smaller than in A and C only the first year. The yields during the second year were irregularly reduced by a spring frost.

Winemaking tests. When the Carignane grapes were mature, approximately 100 pounds from each treatment were brought to Davis and made into wine by the Division of Viticulture. After fermentation, the wine was stored in wood and later in glass. The wine was tasted and analyzed from time to time. There were no outstanding differences in organoleptic quality that could be attributed to the irrigation treatment. In all years, the wine from the vines that were supplied with available moisture throughout the growing season was of the same quality as that from the vines that lacked available moisture for long periods during the growing season. Furthermore, the application of a large amount of water shortly before picking, as was done during the first year, did not affect the quality of the wine in a deleterious way. The wine was a claret type, low to good in color and fair to medium in taste and body. The analyses of the musts and wines are given in table 14.

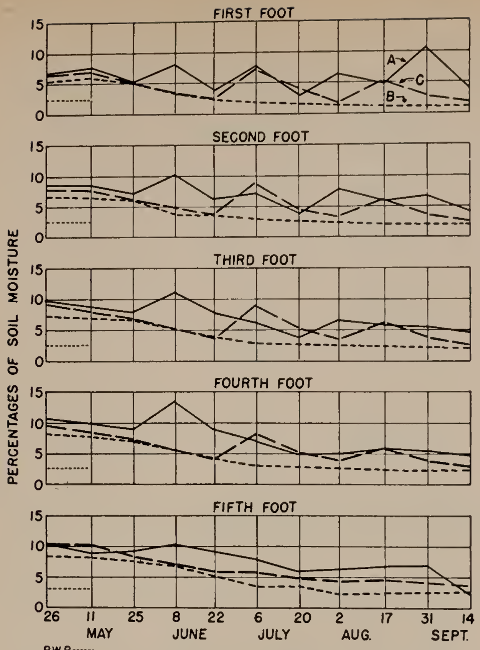


Fig. 11. Soil moisture conditions in the Leek vineyard, third year of trials. The PWP is indicated by the dotted lines at the left. Treatment A was irrigated June 1, June 30, July 27, and August 26; treatment B was not irrigated; treatment C was irrigated June 30 and August 3.

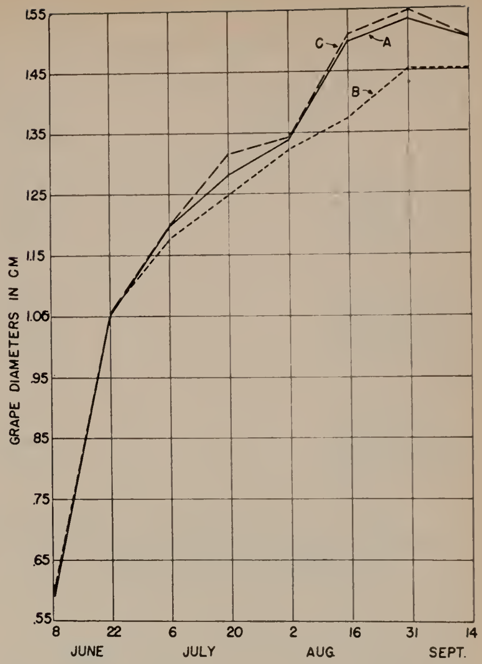


Fig. 12. Sizes of Carignane grapes, Leek vineyard. Third year of trials.

Shelford vineyard. Two plots of 20 Carignane grapevines each were laid out in an irrigation experiment in the Shelford vineyard situated about one half mile east of the Russian River at Cloverdale, Sonoma County. The elevation of the planting was but a few feet above the stream, and this fact may help to explain the soil moisture conditions found in the 5th and 6th foot depths during at least

Table 13. Characteristics of Carignane grapes, Leek vineyard, Hughson.

Treatment	Balling (degrees)	Acid as tartaric (per cent)	Average diameter (cm.)	Average yield (lbs. per vine)
A 1st year	21.1	0.83	1.47	21.7
B 1st year	22.3	0.88	1.39	23.7
C 1st year	22.0	0.70	1.49	25.4
A 2nd year	22.4	0.51	1.44	12.1
B 2nd year	20.6	0.57	1.48	17.4
C 2nd year	23.2	0.48	1.40	13.8
A 3rd year	22.0	0.62	1.50	35.3
B 3rd year	20.6	0.45	1.46	27.2
C 3rd year	23.0	0.54	1.50	28.3

Table 14. Analyses of musts and wines of Carignane grapes, Leek vineyard, Hughson.

Treatment	Balling (degrees)	Acid as tartaric (per cent)	Wine color	Alcohol in wine
A 1st year	21.1	0.83	17.4*†	10.8
B 1st year	22.3	0.88	17.4*	10.6
C 1st year	22.0	0.70	18.0*	10.1
A 2nd year	22.4	0.51	137	11.6
B 2nd year	20.6	0.57	112	9.7
C 2nd year	23.2	0.48	290	11.5
A 3rd year	22.0	0.62	105	11.9
B 3rd year	20.6	0.45	115	11.4
C 3rd year	23.0	0.54	125	12.5

* Data for 1st year obtained by a different method and not comparable with other years, but the color of the three samples in the first year are comparable with each other.
† Color increases as figures increase.

two seasons. The vines were typical of the variety, grown on their own roots, and planted 8 × 8 feet apart. The soil was classified as a Yolo loam, stream bottom phase, but had occasional pockets of coarse sand which caused some irregularities in the soil moisture extraction curves. The experiments were carried on for three years. The average water-holding properties of the soil are given in table 15.

The irrigated plot was watered by constructing a levee around the plot and applying water at intervals during the growing season. Two irrigations were given the irrigated plot in each of the three seasons. These irrigations were applied early in July and in August each year. Under the comparatively mild climatic conditions, the unirrigated plot reached the PWP late in July or early in August in each of the three years. The soil moisture record for the third year is shown in figure 13. The PWP in the dry plot was reached in the top foot about July 15 and at the lower depths about August 12.

Growth of the fruit was obtained from diameter measurements as previously described. The results in the third year are

Table 15. Moisture equivalents, PWPs, and apparent specific gravities of Yolo loam, Shelford vineyard, Cloverdale.

Depth of soil in feet	Moisture equivalent	PWP	Apparent specific gravity
0–1	21.0	9.6	1.30
1–2	16.9	8.4	1.27
2–3	14.1	7.3	1.28
3–4	14.3	8.0	1.31
4–5	13.3	6.4	1.27
5–6	12.3	6.1	1.28

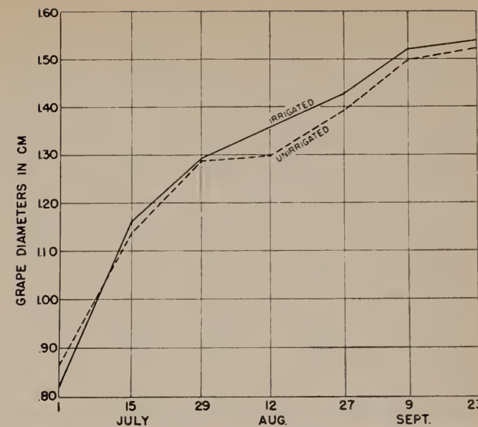
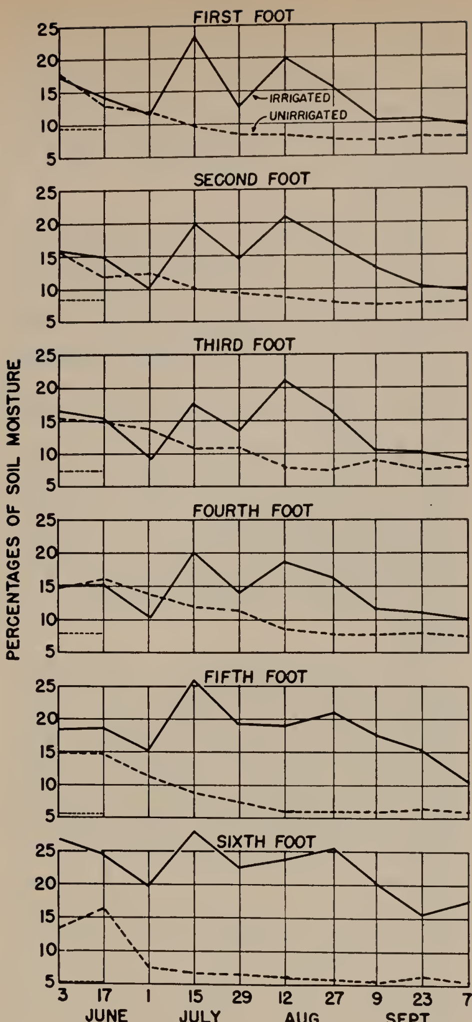


Fig. 14. Sizes of Carignane grapes, Shelford vineyard. Third year of trials.



shown in figure 14. The grapes grew at about the same rate until after July 29. On August 12 the fruit in the unirrigated plot was smaller than that in the irrigated plot. The difference in size was small at the end of the season. In the other two years, the fruit from the dry plot was slightly larger than that from the wet plots, probably because of moisture in the 5th and 6th foot depths and below.

Fig. 13. Soil moisture conditions in the Shelford vineyard, third year of trials. The PWP is indicated by the dotted lines at the left. The irrigated plot was watered July 22 and August 11.

Table 16. Characteristics of Carignane grapes, Shelford vineyard, Cloverdale.

Treatment	Date picked	Balling (degrees)	Acid as tartaric (per cent)	Average diameters (cm.)	Weight per berry (gm.)
Irrigated	1st year Sept. 19	20.0	1.11	1.42	2.25
Unirrigated	1st year Sept. 19	20.6	0.93	1.47	2.10
Irrigated	2nd year Sept. 12	20.1	1.12	1.46	....
Unirrigated	2nd year Sept. 12	20.7	1.11	1.50	....
Irrigated	3rd year Oct. 7	20.5	1.26	1.54	2.23
Unirrigated	3rd year Oct. 7	21.9	1.12	1.52	2.21

The sugar and acid contents, sizes, and weights when picked are given for all years in table 16. The relatively small and not significant differences probably resulted from the fact that the vines in both plots obtained moisture from the 5th foot and below during the growing season. In spite of the fact that the readily available moisture of the dry plot was exhausted in the top 4 feet early in August of the third year, the vines may have obtained enough water from the soil below this depth to grow and mature their fruit at about the same rate as those in the wet plot. Maintaining the soil moisture high in the available range on the average did not produce larger berries or retard the ripening.

Winemaking tests. The wines made from the Carignane vineyard during the three-year period showed only comparatively slight differences in composition between the irrigated and unirrigated lots. The intensity of color was slightly higher in the wines from the unirrigated plots. The analyses are given in table 17.

Carignane and Barbera

Experiments with two varieties of wine grapes, the Carignane and the Barbera, were carried on for two years at the Prati vineyard near Asti in northern Sonoma County. Thirty vines with guard rows constituted each plot. The soil was classified as a Yolo fine sandy loam with pockets of coarse sand or fine gravel. The vineyard was situated a short distance from the Russian River at an elevation of a few feet above that stream. The water-holding characteristics were similar to those described above in the Shelford vineyard.

The irrigated plot was watered once each year about the middle of July. The application was small and moistened the soil to a depth of between 2 and 3 feet. In the dry plot the PWP was reached in the top 2 feet late in August the first year, and to a depth of 5 feet about the middle of September during the second year. Except for the somewhat higher moisture contents in the top 2 or 3 feet following the light irrigations about the middle of July, the moisture conditions in both plots were nearly the same throughout the season.

Under the soil moisture conditions that existed in the vineyard both years, in which the vines in both the irrigated and unirrigated plots had some readily available moisture to a depth of 5 feet or more, at least until the fruit had reached full size, there were no marked differences in sizes of berries. Neither of the unirrigated plots were subjected to long periods of dry soil conditions. The Carignane grapes were about equal in size in both plots each year, while the unirrigated Barbera grapes were slightly larger than the irrigated ones. Furthermore, the cor-

Table 17. Analyses of musts and wines of Carignane grapes, Shelford vineyard, Cloverdale.

Treatment	Date picked	Balling (degrees)	Acid as tartaric (per cent)	Wine* color	Alcohol in wine
Irrigated	1st year Sept. 19	20.0	1.11	157	10.7
Unirrigated	1st year Sept. 19	20.6	0.93	187	11.3
Irrigated	2nd year Sept. 17	20.1	1.12	97	10.1
Unirrigated	2nd year Sept. 17	20.7	1.11	124	10.8
Irrigated	3rd year Oct. 7	20.5	1.26	114	9.6
Unirrigated	3rd year Oct. 7	21.9	1.12	127	10.9

* Color increases as figures increase.

Table 18. Characteristics of Carignane and Barbera grapes, Prati vineyard, Asti.

Treatment	Carignane			Barbera		
	Balling (degrees)	Acid as tartaric (per cent)	Average diameter (cm.)	Balling (degrees)	Acid as tartaric (per cent)	Average diameter (cm.)
Irrigated 1st year	22.2	0.77	1.30	25.7	1.10	1.20
Unirrigated 1st year	22.7	0.68	1.31	25.6	1.04	1.26
Irrigated 2nd year	20.5	0.77	1.25	20.5	1.13	1.18
Unirrigated 2nd year	19.3	0.77	1.27	21.5	1.11	1.29

responding sugar and acid contents were essentially similar each year, as shown in table 18. Here again, the addition of water to the soil, thus increasing the amount in the available range, had no discernible effect on the size or quality of the fruit.

Winemaking tests. Both plots of Carignane and of Barbera grapes at Asti had readily available moisture throughout the growing season, at least until shortly before harvest. The only difference in quality of the wines produced was a slightly higher color value in the wines from the irrigated plots. The analyses are given in table 19.

Early Burgundy

Experiments were carried out for 2 years on two plots of Early Burgundy grapes about one half mile west of Rutherford, Napa County. Each plot consisted of 30 vines surrounded by suitable guards that received the same irrigation treatment as the experimental ones. The vines were vigorous and typical of the variety

Table 19. Analyses of musts and wines of Carignane and Barbera grapes, Prati vineyard, Asti.

Treatment	Date picked	Balling (degrees)	Acid as tartaric (per cent)	Wine* color	Alcohol in wine
Carignane					
Irrigated	1st year Sept. 30	22.2	0.77	182	11.5
Unirrigated	1st year Sept. 30	22.7	0.68	167	11.8
Irrigated	2nd year Sept. 23	20.5	0.77	147	10.5
Unirrigated	2nd year Sept. 23	19.3	0.77	133	10.5
Barbera					
Irrigated	1st year Sept. 21	25.7	1.10	435	13.6
Unirrigated	1st year Sept. 21	25.6	1.04	400	13.4
Irrigated	2nd year Sept. 23	20.5	1.13	286	11.4
Unirrigated	2nd year Sept. 23	21.5	1.11	132	11.2

* Color increases as figures increase.

Table 20. Moisture equivalents, PWPs, and apparent specific gravities of Bale gravelly loam, Inglenook vineyard, Rutherford.

Depth of soil in feet	Moisture equivalent	PWP	Apparent specific gravity
0–1	18.5	10.0	1.38
1–2	18.0	13.0	1.60

and were six years old when the experiment started. They were grafted on Rupestris St. George root and were planted 7 × 10 feet apart. Water was supplied to the irrigated plot by means of a porous canvas hose connected to the domestic supply. Soil moisture samples were taken at bi-weekly intervals to a depth of 5 feet. The soil was classified as a Bale gravelly loam, and the water holding characteristics, obtained in the usual manner from fragmented samples secured with a soil auger, are given for the first 2 feet in table 20. Data for the 3d, 4th, and 5th foot depths are excluded since they do not accurately reflect the moisture values obtained in the field for this soil. This lack of agreement is probably due to the extremely dense character of the soil at these depths. While the moisture content at these depths decreased slightly as the season progressed, it is probable that the decrease was due to slow natural drainage rather than extraction by roots. Laboratory trials (6) showed that sunflower roots were unable to penetrate soils compacted to a density of about the same value as that found in the lower depths of this vineyard.

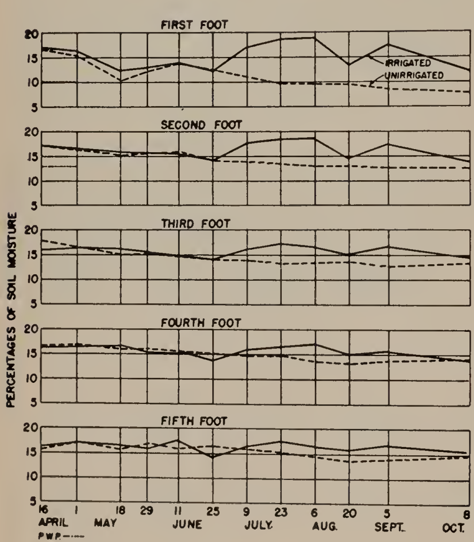


Fig. 15. Soil moisture conditions in the Inglenoon vineyard, first year of trials. The PWP is indicated by the dotted lines at the left. The irrigated plot was watered, by water seeping from a canvas hose, between June 25 and July 2, and again between July 15 and 20; the unirrigated plot was not watered. A rain of 1.2 inches occurred May 30.

The unirrigated plot was not watered during the growing season. The irrigated plot was irrigated (by water seeping from a porous hose) from June 25 to July 2, and again from July 15 to July 20 in the first year's trials, and at about weekly intervals in the second, the last water being applied on August 25. About 1.2 inches of rain fell on May 30 of the first season. The record for the first year is shown in fig. 15.

In the unirrigated plot the loss of water decreased materially in the top foot by July 23, and in the 2d foot by July 9 of the first year. There was some extraction of moisture from the 3d foot. The relatively slight change in moisture contents in the 4th and 5th foot depths, probably represents drainage from saturation to what may be called field capacity of these dense soils. The soil moisture contents below the 1st foot did not reach the PWP as determined in tests with the fragmented soil.

Soil moisture samples taken from under a nearby unirrigated walnut tree

in September showed moisture contents essentially equal to those obtained in the vineyard. Similar results were obtained from samples taken under pine trees that were about 50 years old. The roots of grapevines, of walnut and of pine trees were apparently unable to extract much moisture from the 4th and 5th foot depths.

The growth curves from the grapes in the first year are shown in figure 16. The berries in the unirrigated plot began to grow more slowly than those in the irrigated one between June 27 and July 9, which corresponds with the time when rate of extraction of moisture decreased in the top 2 feet in the dry plot, or when they were at the PWP. The berries in the unirrigated plot were smaller than those in the irrigated one on July 9 and remained so throughout the season. The roots of the vines in the unirrigated plot extracted the readily available moisture from the top 3 feet, but, apparently, used little or none from the 4th and 5th foot depths. The behavior of the vines was similar to that of vines on a shallow soil, even if there was no true hardpan layer present.

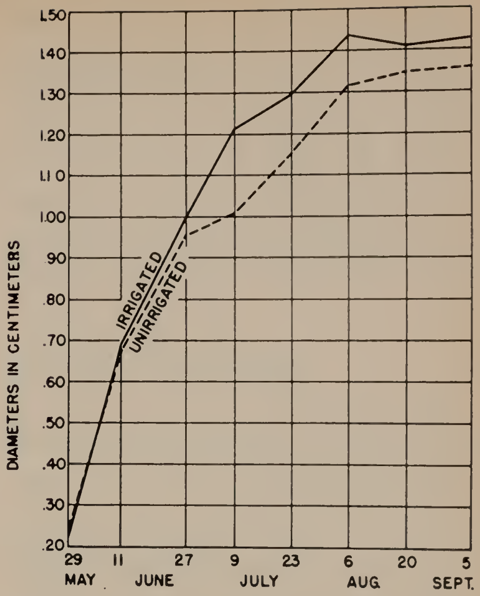


Fig. 16. Sizes of Early Burgundy grapes, Inglenook vineyard. First year of trials.

Table 21. Characteristics of Early Burgundy grapes, Inglenook vineyard, Rutherford.

Treatment	Date picked	Balling (degrees)	Acid as tartaric (per cent)	Average diameter (cm.)	Weight per berry (gm.)
Irrigated	Sept. 19	20.9	0.63	1.43	2.31
Unirrigated	Sept. 19	22.3	0.52	1.36	1.99
Irrigated	Sept. 17	20.2	0.75	1.51	....
Unirrigated	Sept. 17	22.9	0.65	1.37	....

Table 22. Analyses of musts and wines of Early Burgundy grapes, Inglenook vineyard, Rutherford.

Treatment	Date picked	Balling (degrees)	Acid as tartaric color	Wine* color	Alcohol in wine
Irrigated	1st year Sept. 19	20.9	0.63	286	10.8
Unirrigated	1st year Sept. 19	22.3	0.52	385	12.1
Irrigated	2nd year Sept. 17	20.2	0.75	226	10.6
Unirrigated	2nd year Sept. 17	22.9	0.65	412	11.9

* Color increases as figures increase.

The sugar and acid contents, sizes, and weights of the grapes when picked are given in table 21. The sizes of the berries in the unirrigated plot were significantly smaller than those in the irrigated one during both years.

Winemaking tests. The wines from the Early Burgundy grapes in the Inglenook vineyard showed no significant changes in taste, but the color of the wine from the unirrigated plot was considerably darker than that of the irrigated one, possibly due to the small size of the berries in the former, or to the fact that the higher percent alcohol extracted more color from the skins during fermentation. The analyses for both years are given in table 22.

MOISTURE LOSSES: IRRIGATION NEEDS

The soil moisture records secured during the course of these experiments provide an opportunity to estimate the losses of moisture from the soil, and thus irrigation needs. The slopes of the soil moisture curves, of course, indicate the rates at which water is being extracted from the soil. As is usual, however, there are gaps in the data, in studies such as those reported here, where the main objective was to measure the effect of various soil moisture conditions on growth response rather than to obtain records of water use. For instance, following an irrigation, a week or more might have elapsed before samples could be taken. For such periods where data are lacking, estimates of the use of water have been made.

Instead of averaging the soil moisture losses for the several years of each experiment, the year of highest moisture extraction was used. The maximum rates of use are listed in table 23 for each period. Some variation in the use of water was probably due to differences in sizes of the vines in the different experimental plots. The tabulation, admittedly, is based somewhat upon judgment of the authors from their experience during the many years of these experiments. Where evaporating conditions are more severe than in the areas represented by the vineyards listed in the table, larger amounts of water may be required.

Applying the amounts shown in the table should provide readily available water throughout the season for the different localities where the experiments were conducted. It should be kept in mind that these amounts do not include additional water which must be provided to take care of the waste in conveyance in application and in evaporation during the time of application. The evaporation from the soil surface, however, is a relatively small part of the total amount taken from the soil. Transpiration by the plants accounts for most of the loss.

The moisture stored in the soil from rainfall will carry the vines through the early part of the season. For example, at Davis enough rain falls and can be stored in the upper 6 feet of Yolo soil to provide the 10.8 inches of readily available water needed by the plants until about the middle of July. At some of the other localities irrigation may be necessary earlier if the rainfall is too low or if the water-storage capacity of the soil is not sufficient to store the needed water. The quantities in table 23, then, represent the amounts of water which need to be applied—less the water stored from rains but plus the wastes incurred in applying the water. Whether this amount will require one or more irrigations will be governed by the depth at which the soil is almost reduced to the permanent wilting percentage, and on the moisture properties of the soil. Taking the Yolo soil again as an example, if there are 10.8 inches in storage in the soil from the rains, about 8 inches should carry the vines through the season.

Table 23. Loss of water from soil by evaporation and transpiration in acre-inches per acre.

	Wood		Leek		University Farm		Shelford		Diekman	
	THOMPSON SEEDLESS		CARIGNANE		MUSCAT		CARIGNANE		TOKAY	
	For period	Cumulative	For period	Cumulative	For period	Cumulative	For period	Cumulative	For period	Cumulative
April	0.4*	....	0.4*	....	0.5†	....	0.3†	....	0.5†	....
May 1–15	0.8	1.2	0.7	1.1	1.3	1.8	1.4	1.7	1.3	1.8
May 16–31	0.9	2.1	1.2	2.3	1.4	3.2	1.7	3.4	1.4	3.2
June 1–15	2.5	4.6	1.3	3.6	2.1	5.3	1.7	5.1	1.4	4.6
June 16–30	3.0	7.6	1.3	4.9	2.1	7.4	2.5	7.6	2.5	7.1
July 1–15	3.2	10.8	3.4	8.3	3.4	10.8	2.5	10.1	3.4	10.5
July 16–31	2.5	13.3	3.3	11.6	2.5	13.3	2.2	12.3	2.8	13.3
Aug. 1–15	2.4	15.7	2.4	14.0	1.6	14.9	2.1	14.4	2.3	15.6
Aug. 16–31	2.3	18.0	2.3	16.3	1.5	16.4	2.1	16.5	2.3	17.9
Sept. 1–15	1.1	19.1	2.0	18.3	1.4	17.8	1.8	18.3	1.5	19.4
Sept. 16–30	0.7	19.8	0.4	18.7	0.5	18.3	1.1	19.4	0.9	20.3
Oct. 1–31	0.6	20.4	0.3	19.0	0.5	18.8	0.8	20.2	0.6	20.9

* Loss by evaporation and transpiration from upper 5 feet of soil.
† Loss by evaporation and transpiration from upper 6 feet of soil.

DISCUSSION

The experiments on the irrigation of grapes were carried out in seven grape-growing areas on six soil types, under widely different climatic conditions. Experimental plots were located near Arvin, Fresno, Modesto, Lodi, Davis, Rutherford, Cloverdale, and Asti. The grapes under trial included raisin, table, and wine varieties. They were Thompson Seedless, Emperor, Carignane, Tokay, Muscat, Early Burgandy, and Barbera. The soils included members of the Arvin, San Joaquin, Fresno, Hanford, Yolo, and Bale series. The climatic conditions varied from the hot dry interior valley conditions at Arvin and Fresno through the moderate conditions at Modesto, Lodi, and Davis to the relatively cool conditions in the north coast counties at Rutherford, Cloverdale, and Asti.

Certain variations in response were obtained from the soil moisture conditions brought about by differences in irrigation treatment, while others seemed to be closely associated with the climatic conditions. The variations associated with soil moisture conditions were those related to yields, size of fruit and in a few cases retardation of maturity as shown by the color and sugar content. In no case, however, were these responses obtained unless the soil moisture was reduced to the PWP and remained there for a considerable period. The principal variations associated with climatic conditions were the differences in time of ripening which varied from season to season, and these responses were the same in both the irrigated and unirrigated plots.

Soil moisture and wine analyses

Analyses of the wines from the varieties ordinarily used in winemaking showed some seasonal variation depending on the ripening season, and the time of picking. For example, grapes picked early or in midseason during a year of late ripening showed a different composition from those allowed to fully mature during a normal season. In most cases the grapes from both the irrigated and unirrigated plots reached normal maturity about the same time, and the wines were essentially similar in quality. In a few instances, as for example with the Early Burgundy variety at Rutherford, the grapes from the unirrigated plot reached maturity before those in the irrigated one, and there was a slight difference in the composition of the wines. Judging from results in the other experiments, if picking had been delayed a few days, it is probable that the grapes from both treatments would have had had approximately the same composition. The color of the wine seemed to be associated with the size of the berries, with the better color derived from the small-sized berries. The size of the berries was only affected when the soil moisture was reduced to the PWP during the growth period. This is a case in which a quality characteristic was influenced by the irrigation treatment. It should be pointed out that when the berries from both treatments were approximately equal in size, the colors of the wines produced were about the same.

Soil moisture and yields

The records of the relation of soil moisture to yields presented in this report are incomplete, largely because of the difficulties in obtaining yield records when the experimental plots are located at considerable distances from Davis. In most cases where such records were obtained, the results indicate a reduction in yields of the unirrigated plots when the soil moisture in those plots was reduced to the PWP and kept there for a considerable period. The previous production records of the vines were unknown, and it

is possible that there was considerable variability in the various plots. The yield records presented are average yields and are given without statistical treatment, as yields from individual vines were not available. The results for the Thompson grapes from the Wood vineyard indicate a larger yield from treatment A, which was kept moist continuously, than from the other two which were without readily available moisture for varying periods of time. In the case of the Emperor grapes, the yields in the dry treatment were not reduced the first year, because this treatment had some available moisture at least until shortly before harvest. In the second year the results were inconclusive. The results from Carignane grapes in the Leek vineyard show that treatment A yielded more than the other two during the third year of differential irrigation. Although the dry plot reached the PWP early in the season during the first year it was irrigated almost immediately for fear of injuring the vines, and the yields were about the same as those in the irrigated plot. The results during the second season are inconclusive, because a spring frost reduced the crop irregularly. The record for the Muscat variety at Davis during a four-year period clearly shows a reduction in yield in the dry plot.

Soil moisture and growth of fruit

The individual berries in a cluster of grapes ordinarily attain maximum size two to eight weeks before they are picked. In some of the varieties there are three distinct periods of growth similar to those in drupaceous fruits.

Measurements of grape berries during the season show several interesting features. Most grape varieties, apparently, are deep rooted, and, if water is available from the deep layers, lack of readily available moisture in the top 3 or 4 feet may not cause an appreciable slowing down in growth of the fruit. The most pronounced results were obtained in shallow soils where the roots could not penetrate deeply because of the impervious layers below. Differences in size of berries were obtained with Early Burgundy in the Inglenook vineyard, with Carignane in the Leek vineyard at Hughson, and with Muscats in the University of California vineyard at Davis. In the latter case, the Muscats were apparently shallow rooted, and showed distinct wilting even if there was readily available moisture below six feet. In the other experiments on deep soils the records show some available moisture, at least, until harvest or shortly before, and little or no differences in berry size.

Soil moisture and sugar content of fruit

Widely different soil moisture conditions did not seem to markedly influence the sugar content of the fruit, except in a few cases. In these instances there was a slight delay in maturity, as the vines in the moist treatments were strongly vegetative and the fruit was densely shaded. The lack of readily available moisture did not seem to influence the sugar content that the grapes finally attained. In a few cases, the grapes from the wet plots seemed to reach this sugar content a little later than those from the dry ones. In most cases, if picking was delayed a short time, the fruit from both the wet and dry plots reached about the same sugar content A short delay in picking is ordinarily not important except in table varieties for early market or in case of danger from early fall rains that interfere with the drying or the harvest for wine.

Soil moisture and drying ratios

The drying ratios were not materially affected by the irrigation treatments given the various plots. This result is to be expected inasmuch as the sugar contents were essentially equal in all treatments. In several instances, the grapes in the dry

treatments were partly dried on the vines before they were picked, and hence the results obtained indicated a favorable drying ratio from these plots. There were no differences in the quality of the raisins produced.

MOISTURE EXTRACTION AND IRRIGATION INTERVALS

Reduction of the soil moisture from winter rains or irrigation during the dormant period occurred at different times depending on the climate and on the type of soil. In general, the PWP was reached earlier in the season on sandy types of soil in the interior valley than on the loams, or in the vineyards in the relatively cool north coastal regions. In some cases the readily available moisture from the winter rains was exhausted early in June on light soils in the San Joaquin Valley, early in July at Davis, and in the middle of August on deep soils in Napa and Sonoma counties.

A safe interval between irrigations seems to be about three to four weeks on light soils in the interior valley, and about five to six weeks at Davis. In the north coast counties, on deep soil, no summer irrigation may be necessary in some instances, while in others a single watering during the summer may be sufficient.

The results of these irrigation experiments with grapes are a further substantiation of the results obtained by the authors with deciduous fruits of various sorts (9), which show that the growth of fruit and its quality are not affected by irrigation unless the moisture content in the soil in contact with the roots is reduced to the PWP, and that good irrigation practice is to irrigate only frequently enough to keep the soil moisture from reaching the PWP.

SUMMARY

1. Irrigation shortly before harvest did not affect the keeping quality, flavor, or drying ratio of the table and raisin varieties tested. Storage qualities of the Thompson Seedless, Tokay, and Emperor varieties were not affected by the irrigation treatment. There were no visible differences in either the Thompson Seedless or Muscat raisins produced under the different irrigation treatments. The wines from the grapes from both wet and dry treatments were remarkably similar if the fruit was allowed to reach maturity.

2. Keeping the soil continuously moist sometimes delayed maturity of the fruit for a short time. On the other hand, sizes of berries were usually smaller in the plots where the moisture in the soil containing most of the roots was reduced to the PWP and remained there for a considerable time while the fruit was growing. When the size of the berries was reduced by lack of readily available soil moisture, the wines generally had a darker color.

3. So long as readily available moisture was continuously present, the sizes of the grapes were not affected by the irrigation treatment. The moisture needs of the vine will be served if the moisture content of the soil in contact with the roots is not allowed to reach the PWP and remain there for an appreciable period. Good irrigation practice consists in withholding the application of water until readily available water is nearly depleted, taking into consideration the time necessary to apply the water over the area involved.

4. The safe interval between irrigations for grapes during the summer was found to be about the same as for tree fruits: about three to four weeks on light soils in the interior valley, five to six weeks at Davis, and a single watering or none at all in the north coast counties on deep soil.

LITERATURE CITED

BIOLETTI, F. T.

1. 1905. Manufacture of dry wines in hot countries. Calif. Agr. Exp. Sta. Bul. 167: 1–66. (Out of print.)
2. 1921. Vineyard irrigation in arid climates. Calif. Agr. Exp. Sta. Cir. 228: (Out of print.)

BIOLETTI, F. T., and E. H. TWIGHT

3. 1901. Report of conditions in vineyards in portions of the Santa Clara Valley. Calif. Agr. Exp. Sta. Bul. 134:1–11. (Out of print.)

HENDRICKSON, A. H., and F. J. VEIHMEYER

4. 1931. Irrigation experiments with grapes. Amer. Soc. Hort. Sci. Proc. 28: 151–57.

JACOB, H. E.

5. 1940. Grape growing in California. Calif. Agr. Ext. Serv. Circ. 116:1–80.

VEIHMEYER, F. J., and A. H. HENDRICKSON

6. 1946. Soil density as a factor in determining the permanent wilting percentage. Soil Sci. 62:451–56.
7. 1949. Methods of measuring field capacity and permanent wilting percentage of soils. Soil Sci. 68:75–94.
8. 1950. Soil moisture in relation to plant growth. Plant Physiol. Ann. Rev. 1:285–304.
9. 1950. Essentials of irrigation and cultivation of orchards. Calif. Agr. Ext. Serv. Circ. 50:1–24.

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